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Wind Turbine Design Project

Developed by Rebecca Ostman

Description:
In this lesson students will learn about how wind turbines work and some of the challenges involved in designing them. Students will also learn about the design process and engineering trade-offs by designing their own model wind turbines.

Prerequisites:
Students should know what energy is and that it can be converted from one type to another.

Instruction Time:
This lesson requires about 1½-1¾ hours to complete.

Audience:
This lesson was designed for middle school students, grades 6-8.

Lesson Objective:
Students will get an introduction to engineering and the design process.

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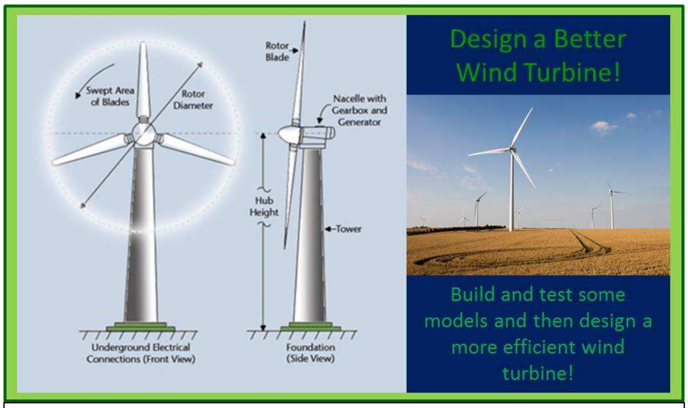


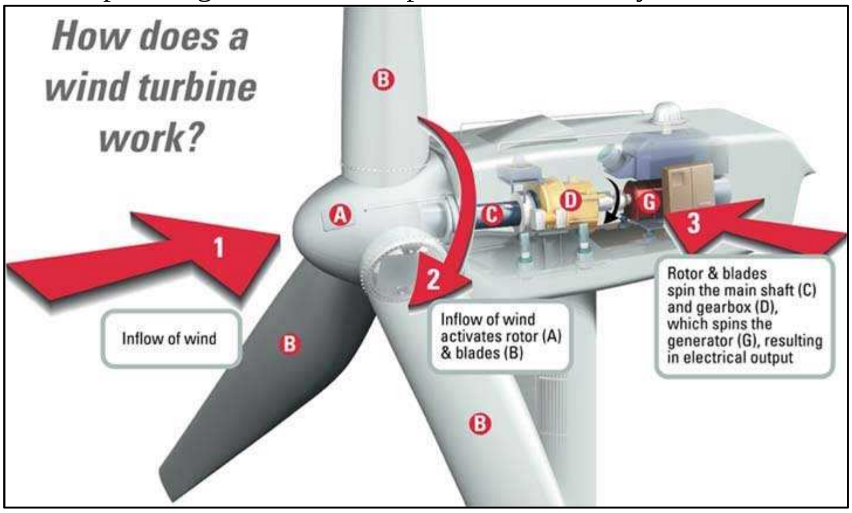
Wind turbines get power from the wind, but the wind is constantly changing. Ever wondered how an engineer would design a wind turbine to produce electricity in both low speed and high speed winds? Design, build, and test your own prototypes (models) to find out!

Lesson Overview:

In this lesson students will learn about *how wind turbines work*, *how they convert the energy* from the wind into energy that we use every day in our homes and schools. They will also learn about some of the *challenges involved in designing wind turbines*, especially wind variability. They will *build a model* wind turbine and *test* its electrical output at both low and high wind speeds. Then they will explore changing some aspects of its design. They will learn that it is important to test only one design change at a time in order to *isolate the variable*. They will *build and test* another model with one aspect of its design changed and observe the effect this has on the performance of the wind turbine. They will then *share their results* with their classmates, and based on the results of the entire class, students will come up with an *optimal design*. However, before they can build this optimal design, they will have to *take into account a cost constraint*. With that constraint in mind, they will *build a final design* and test its performance.

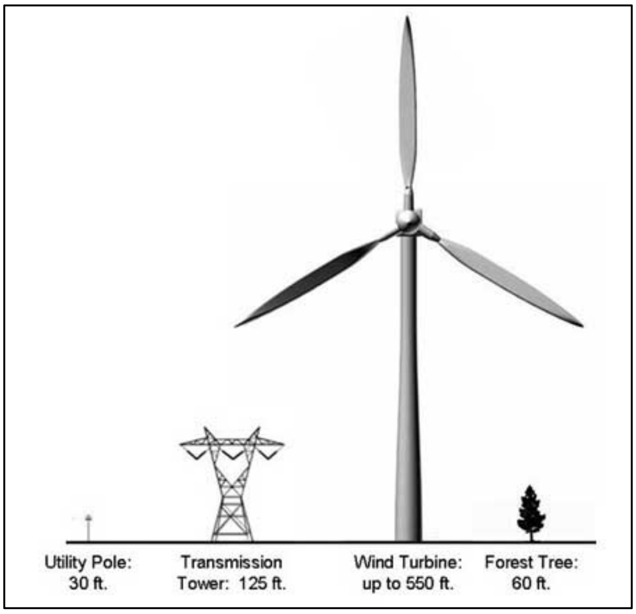
Background Information:

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy, which is then converted to electrical energy by a generator, usually in the hub of the turbine. If the mechanical energy is used to drive machinery, for example to grind grain or pump water, it is referred to as a windmill. For most wind turbines the wind moving over the blades, creates lift, which is the force that turns the blades. The blades turn the rotor which turns the shaft and gearbox. These spin the generator which produces electricity.



http://claesjohnsonmathscience.wordpress.com/article/how-a-wind-turbine-works-yvfu3xg7d7wt-27/

Wind turbines come in many different types and sizes; they can be small enough for auxiliary power on a boat or large enough to contribute significant power to the grids that power towns and cities. The largest wind turbines are in wind farms offshore.



http://ckwag.org/issues.html

Wind turbines come in two main types: horizontal axis and vertical axis. Horizontal axis wind turbines are the ones most people are familiar with; these are the ones in the wind farms we see. Their blades rotate about the horizontal axis. Vertical axis wind turbines rotate about their vertical axis. These are advantageous because wind direction does not matter, however there are other problems with them, such as an inherently lower power coefficient (lower power output for their size) and pulsating stress on the drive train. These are usually used in urban areas on top of buildings.

Vertical Axis Horizontal Axis

http://windturbinezone.com/wind-turbine/horizontal-wind-turbine
http://construction.about.com/od/Green/ig/Center-for-Sustainable-Landscapes/Vertical-Axis-Wind-Turbine_CREDIT-Alexander-Denmarsh-Photography.htm

Currently the U.S. produces 143.5 terrawatt-hours of wind power per year, which is about 3.53% of all of its electricity. However, this is a growing branch of the energy industry and those numbers are expected to go up. According to the National Renewable Energy Lab, the U.S. has the capacity to produce 37 pentawatt-hours annually, which is nine times the current total consumption of the U.S. Many other countries produce significant amounts of electricity using wind power. In Denmark, a world leader in wind power production, 18.9% of the country's power was produced from wind and their goal is for 50% of their power to be produced from wind by 2020. Wind power is about 15.9% of Spain's total power consumption, 8% of Germany's, 5.3% of the United Kingdom's, 2.4% of Australia's, and 5% of New Zealand's.

Learning Objectives & Assessment:

Students will be able to:	Assessments
1. *Describe* a wind turbine including its purpose and basic parts	- class discussion - whiteboard activity - worksheet
2. *Identify* some of the challenges involved in designing a wind turbine.	- class discussion - worksheet
3. *List* some parameters that can be varied in wind turbine blade design.	- class discussion - constructed wind turbines - worksheet
4. *List* different types of energy involved in wind turbine operation.	- class discussion - worksheet
5. *Explain* why it is important to change only one variable at a time when testing the performance of their wind turbines	- worksheet
6. *Choose* an 'optimal' design based on the evaluation of the wind turbine performance.	- worksheet
7. *Explain* what a trade-off is and give an example of one in their life.	- class discussion - worksheet
8. *Balance* the cost and the desirable wind turbine traits in choosing an 'optimal' wind turbine design.	- redesigned wind turbine - report to class - worksheet

Alignment to NRC Framework:

Scientific and Engineering Practices

- Planning and Carrying Out Investigations
  - Collect data and generate evidence to answer scientific questions or test design solutions under a range of conditions.
  - Collect data about the performance of a proposed object, tool, process or system under a range of conditions.
- Constructing explanations (for science) and designing solutions (for engineering)
  - Optimize performance of a design by prioritizing criteria, making tradeoffs, testing, revising, and re-testing.

Students measure the voltage of their wind turbines at two wind speeds. They also test multiple different types of wind turbines and then using that data come up with an optimal design.

Crosscutting Concepts

- Energy and matter: Flows, cycles, and conservation
  - Energy may take different forms (e.g. energy in fields, thermal energy, energy of motion)
  - The transfer of energy can be tracked as energy flows through a designed or natural system.

Students learn about and test the conversion of kinetic energy from a fan to electrical energy from their wind turbine. They can feel the wind from the fan, see this wind turn the turbine blades, and then measure the output voltage.

Disciplinary Core Ideas

- Engineering, technology, and applications of science
  - ETS1: Engineering design
    - ETS1.B: Developing possible solutions
    - ETS1.C: Optimizing the design solution

Students build various prototypes which test different design variables and then use the results of those tests to come up with an optimal wind turbine design, within an imposed cost constraint.

Vocabulary:
Renewable Energy – Energy that comes from resources that are continually replenished.
Kinetic Energy – The energy of an object that it possesses due to its motion.
Rotational Energy – The energy of an object that it possesses due to its rotation.
Electrical Energy – The energy carried by moving electrons; we most often use it as electricity.
Prototype – A scaled down, initial model of an object, typically a machine.
Baseline – The existing or unchanged version of an object.
Variable – An element or feature that can be changed.
Trade-off – An exchange of one thing in return for another; compromise

Materials:
Paper Resources
- Student assessment worksheets, 1 per student
- Data table worksheets, initial models, 1 per group
- Construction instructions and Design Guides, 1 per group
- Data table worksheets, redesigned model, 1 per group

See Appendix for all worksheets

Technology & Multimedia Resources
- Power Point presentation, (this is not a requirement), if there is no computer/projector, the instructor should just make a chart on the whiteboard/blackboard for the students to share their results with each other. The slides are provided as separate document from iRise.

Physical Resources
Re-usables

- Individual whiteboards and markers, 1 of each per group.
- Scissors, 1 per group.
- Rulers, 1 per group.
- Markers, 1 per group.
- Hot glue guns, 1 per group, these can be bought at any craft/hobby store they are usually $2-5 per gun for the lower temperature ones, which are definitely the ones that should be used.
- Turbine bases*, I had 2 for 4-5 groups and this worked pretty well.
- 3 speed box fans, one for each turbine base.
- Multi-meters, one for each turbine base.
- LED indicator circuit*, only need 1.
- Blade stencils*, 2-3 per group, which type depends on which turbines each group is building, these also may have to be replaced occasionally if they get damaged.

*See Appendix for materials and building instructions

Consumables
- Poster board, use the thin poster board, not the thick card/foam board that the tri-fold poster boards are made of; this is sometimes sold in smaller sheets, which is recommended. I even only gave ½ (shortwise, hamburger style) a small sheet to each group, in order to cut down on waste.
- Cardstock, ½ (shortwise, hamburger style) sheet per group, only the group(s) that are building a model with the Lighter Material will need this at all.
- Wooden craft sticks, 9 per group, extras will be needed by the group(s) building models with 4 blades.
- Turbine hubs*, 3 per group, which type depends on which turbines each group is building, these will be reusable if the turbines are carefully taken apart after each use, but they will definitely have to be replaced after a few uses.
- Hot glue sticks, 2-3 sticks per group, these can be purchased at the same place as the hot glue guns
*See Appendix for materials and building instructions

Lesson plan:

This lesson is composed of three modules, which can be taught in one day or split over multiple days.

Module 1: Wind turbines

Objectives

1. Students will be able to *describe* a wind turbine including its purpose and basic parts.
2. Students will be able to *identify* some of the challenges involved in designing a wind turbine.
3. Students will be able to *list* some parameters that can be varied in wind turbine blade design.
4. Students will be able to *list* different types of energy.

Engage (3 min)

Begin the lesson with a discussion of renewable energy. Ask if any of them know what renewable energy means (energy whose source can be renewed within our lifetime). Ask students why renewable energy is important for us and our society (we use energy a lot, we don't want to run out of energy, we want our energy production to be environmentally friendly). Ask for some examples of renewable energy sources (hydro, geothermal, solar, wind). When wind power is mentioned, say that wind turbines are going to be the topic of this project.

Explore (7 min)

To introduce students to wind turbines ask if any of them have seen the wind farms off 57 on the way to Chicago or in other places in the surrounding area (hopefully some of them have); show the first slide of the Power Point presentation, which is pictures of actual wind turbines. Ask them to think about how wind turbines make electricity; have them work in small (2-3) groups and draw how they think this process works on the whiteboards. After a few minutes, have a couple groups share what they came up with. Ask what kinds of things might influence how well wind turbines can produce electricity (wind speed, wind consistency, wind direction, wind turbine design). Ask what things an engineer might change in the design of the wind turbine to try and improve its performance (turbine blade length, shape, material, angle into the hub, etc.).

Explain (5 min)

Explain the conversion of energy using the next Power Point slide. Have the students help fill in the types of energy involved in the operation of a wind turbine. *Kinetic energy* from the wind is converted to *rotational energy* by the blades which turn the generator. The generator converts the *rotational energy* to *electrical energy*, which we can use as electricity. Set up the fan and a fully constructed (baseline) wind turbine, connected to the light up circuit. Turn the fan on to its high speed setting (3). Show the operation of the wind turbine and the conversion of energy from the wind created by the fan to electricity which lights up the LEDs. Turn off the fan and turn it back on at low speed (1); let the students see how it might be difficult for the turbine to get started at low wind speeds. Additionally, less LEDs will be lit up.

Elaborate (13-14 min)

Have one student read the first paragraph of the worksheet and another read the second paragraph. Ask if anyone knows what a prototype is; explain that it is a scaled down model of an actual object. Explain that they are going to first build a baseline prototype, which means they are building a prototype of the 'existing' wind turbine, which they will then change. Explain that they will need to determine the performance of the baseline first so that they have something to compare their changed prototypes to. Split the students into groups of 3 (4 is ok, but 3 is better). Explain how to build the wind turbine prototypes; I recommend giving very detailed instructions and even showing them examples of each step; the fourth slide of the Power Point has the construction instructions. It also works fairly well to have the students assign tasks within the group, such as, one student trace out the blades, one student cut them out, and one student measure and mark the wooden craft sticks and glue the blades to the sticks. The student who cut out the blades can inert them into the hub and the one who traced the blades can then glue them to the hub. Each group should construct a baseline model.

Once the students have mostly constructed their models, explain how they are going to test them using the fans and the multi-meters; the directions for this are on the fifth slide of the Power Point. As the groups finish construction, have them test their turbines and have them report their results to the class on a chart on the board, which is on slide 6 of the Power Point.

Evaluate (1-2 min)

Each student should complete the worksheet for Module 1. Each group should have a page of data tables, and the first one (Baseline) should be filled out.

Once the students have pretty much completed reporting the results of their testing, begin Module 2. If they are not quite done, they can finish constructing and testing the baseline in Module 2.

Module 2: Obtaining and Evaluating Data
Objectives

5. Students will be able to *explain* why it is important to change only one variable at a time when testing the performance of their wind turbines.
6. Students will be able to *choose* an 'optimal' design based on the evaluation of the wind turbine performance.

Engage (3 min)

Ask students to think about a time when they have had to choose between two similar products, such as a 4th generation iPod touch or a 5th generation one. The 5th generation one has a new, more efficient processor and a new type of battery. Because of these things, the 5th generation can go much longer without being charged. Ask students which thing, the new, more efficient processor or the new type of battery is responsible for this change. If they say one or the other, ask how they know. Explain that in order to know which one increases the battery life, or if both of them do, they would need to test the processor and the battery individually.

Explore (5 min)

Have the students, in their groups, answer the following questions on their whiteboards:

- What kinds of things they could change in the design of their wind turbines to make them perform better? (Blade length, shape, material, number, angle, etc)
- How does the speed of the wind influence the performance of the wind turbine? Will it perform better at high or low speed? (will produce more power at high speed)
- What problems might a wind turbine encounter if the wind speed is too low or too high? (If the speed is too low, wind turbine might not start spinning, if it does will not produce much power. If the speed is too high, the wind turbine might break)

Explain (1 min)

Explain that the things they are going to change, the variables, in the design of their wind turbines are the length of the blades, the shape of the blades, the number of blades, the material the blades are made of, and the angle at which the blades face the wind, but they are only going to change one thing at a time so that they can see the effect of each variable individually. Because there are a lot of variables, each group is only going to test one variable and then share their results with the class. Have the students make predictions about how they think each variable is going to affect the performance of the wind turbine and fill this out in the worksheet.

Elaborate (16 min)

Assign a variable to explore to each group; it's ok to have more than one group looking at one variable, as long as at least one group is looking at each one. Have the students construct and test a wind turbine with their assigned variable changed. Have each group report their results to the class.

Evaluate (5 min)

Each group should fill out their data table for their variable turbine. Based on the results of the entire class, each group should come up with an 'optimal' design that maximizes voltage output at both low and high speeds. Have them fill out their Module 2 worksheets.

Once they have finished their worksheets, begin module 3.

Module 3: Engineering Trade-offs
Objectives

7. Students will be able to *explain* what a trade-off is and give an example of one in their life.
8. Students will be able to *balance* the cost and the desirable wind turbine traits in choosing an 'optimal' wind turbine design.

Engage (2 min)

To start the discussion about a trade-offs, ask the students about an experience in their everyday life, such as spending time on homework vs. spending time with their friends. If they spend all their time with their friends, then they get bad grades, but if they spend all their time doing homework, then they won't have any friends; it's important to find a balance.

Explore (2 min)

Ask students to come up with examples of other trade-offs in their lives. Then ask if they can think of any trade-offs an engineer might face, in the design of wind turbines or anything else.

Explain (2 min)

Give the example of cost as an actual engineering trade-off; this trade-off is seen in almost all areas of engineering. An optimal design is usually very expensive so an engineer must balance the performance of their design with the cost to produce it. Explain that they are going to have to do the same thing; changes to the baseline design are expensive, so they can only change two things from the baseline design.

Elaborate (14-16 min)

Have the students decide on a design for an 'optimal' wind turbine that only involves two changes from the baseline. Then have them construct it and test it at both wind speeds. They should again report their results to the entire class. This can be made into a competition, with the group getting the highest output voltages (at one or both speeds) winning a prize.

Evaluate (8-10 min)

Have one person from each group verbally report on their group's final design. Their report should include what design they chose, and its output voltage at both wind speeds. Discuss the results and talk about what things and/or combinations of things did the best. The data table for the re-designed turbine should be completed and the students should complete their Module 3 worksheets.

Additional Information and Links:

Wikipedia on wind turbines: Good, basic overview
http://en.wikipedia.org/wiki/Wind_turbine

National Renewable Energy Laboratory: Current research being done on wind power production
http://www.nrel.gov/wind/

Other wind power lessons and resources:
http://www.windpoweringamerica.gov/schools_teaching_materials.asp

Appendix:

Tips for the teacher:

- Making the groups before the lesson is a good idea. However, if your students don't focus very well, it may be a good idea to have them sit in rows for the start of each module for the discussion and then get in their groups once the discussion is over.
- The turbine towers are pretty easy to disassemble and so can be kept in a tub along with the other lesson materials.
- A good way to save time and reduce the confusion during construction is to make kits and put the supplies in baggies and then just hand each group a baggie. Each bag should have the correct blade stencil, the right number of wooden craft sticks, the correct turbine hub, and an extra hot glue gun stick. You can also use paper clips to attach the right kind of blade material to the bag. Make sure to label the bag with the type of turbine that it contains parts for. This insures that groups are making the correct turbine with all the correct parts. This isn't feasible for the third module, in which the students can choose which design variables to use.
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Extension Lesson: Module 1.5: Efficiency

This lesson teaches the equation for efficiency, which is fairly complex for middle school students. It is recommended that this only be taught to advanced classes of students, or possibly, jointly with a math class. It is recommended that students be familiar with the equation for area, exponents (at least squaring and cubing), and algebraic variables.

Objective

1. Students will be able to define efficiency and calculate it using an equation.

Additional materials for this module:

- Calculators
- Extension worksheet

Engage (1-2 min)

To introduce the concept of efficiency, ask students if their parents own a car and ask if their parents are concerned with the car's gas mileage. Ask if anyone knows what gas mileage is and why it is important. Explain that gas mileage is a measure of a car's efficiency and efficiency is the topic of this lesson.

Explore (3-4 min)

Ask students if there are other ways to measure the efficiency of a car. Ask students for examples of other things whose efficiency is important and ask what they think efficiency is, in general. Ask students to come up with things that may be used to calculate the efficiency of a wind turbine. Ask students if they think it is possible for a wind turbine (or anything else) to be 100% efficient.

Explain (7 min)

Explain that efficiency in general is a ratio of some kind of output, usually power or energy, over some kind of input, again usually power or energy; for a car, you put gas in and get miles out, hence the miles per gallon measure of efficiency. The efficiency of a wind turbine is the ratio of power or energy out over the power or energy in. The energy out is the electrical energy produced by the turbine and the energy in is the kinetic energy from the wind. Write the equation for wind turbine efficiency on the board and explain each of the terms

$$\eta = \frac{Power\ out\ (electricity)}{Power\ in\ (wind)} = \frac{i * V}{\frac{1}{2} * (\rho * A * v^3)}$$

Where, η is efficiency, i is the current, V is the voltage, ρ is the density of air, A is the area of the circle made by the spinning blades, and v is the wind velocity. You may need to remind them of the equation for area ($A = \pi r^2$). Walk through the example problem in the extension Power Point slides and have the students follow along with the practice problem on the worksheet.

Elaborate (15 min)

Have the students calculate the efficiency of their baseline wind turbines. This will require them to also measure the current, in addition to the voltage and the length of their blades, which is the blade radius. For wind velocities use 4.3 m/s for the low speed and 6.4 m/s for the high speed. Efficiency can now be used instead of just voltage as a measure of the wind turbines' performance.

Evaluate (3 min)

Have the students complete the extension worksheet. Once they have completed construction and tested their additional wind turbines, they should calculate the efficiencies of those as well.

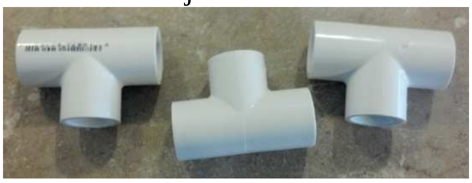
Turbine Tower Construction

For each turbine tower:

What you need:

- 1x ½” diameter PVC pipe, 10 ft. long (this is enough for two turbine towers)
- 4x ½” PVC 90° turn

- 3x ½” PVC T-joint



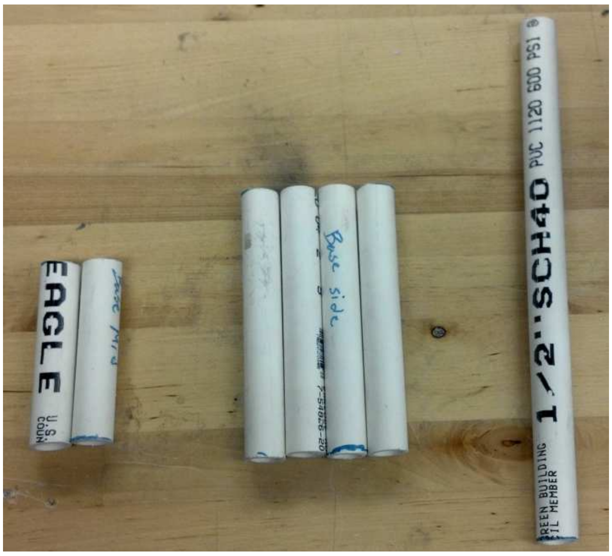
- 1x 1” to ½” 90° turn (I could only find this with the ¾” side threaded, which is fine)

All of the PVC cost under $6 for one turbine tower.

- Hacksaw/handsaw
- Sandpaper
- Gorilla glue
- Drill with ¼” drill bit
- 1x KidWind generators, $5 each, http://store.kidwind.org/wind-energy-kits/parts-materials/parts-to-build-a-turbine/wind-turbine-generator

Instructions:

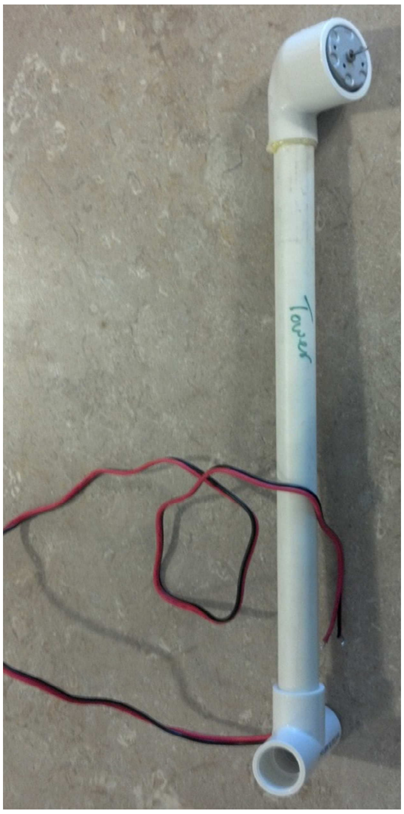
1. Cut the PVC pipe into 1x 15” section, 2x 6” sections, and 4x 8” sections. There is enough PVC for 2 turbine towers. Sand the ends of each section to get rid of all the PVC flakes.



2. Glue the 1” to ½” 90° turn to one end of the 15” section.

3. Drill a hole into the side of one of the ½” T’s.

4. Feed the wire from the generator from the 1” to ½” turn, through the 15” section, and out the hole drilled in the T. Pull the wire tight so that the generator sits just inside the 1” part of the turn.



5. Attach one ½" turn to each of the 8" sections. Attach the remaining ½" T's to the 6" sections.

6. Connect 2x 8" sections with the ½" turns to the other ends of each T.

7. Connect the 6” pieces to the T at the base of the 15” section. Adjust everything so that the turbine tower stands straight up and all the feet are on the ground.

8. Don’t glue any of the other joints together so that the tower can be disassembled for easy storage.

Blade stencils

I made the stencils out of old cereal boxes, which are sturdy enough. Definitely make sure you label each stencil. You need enough Baseline stencils for each group to have one. I made enough of each of the stencils for each group to have one, but this is likely to be excessive, but if each of the groups wanted to make Round Blades (for example) for their re-design I wanted to have enough of them. See the attached page for the blade templates.

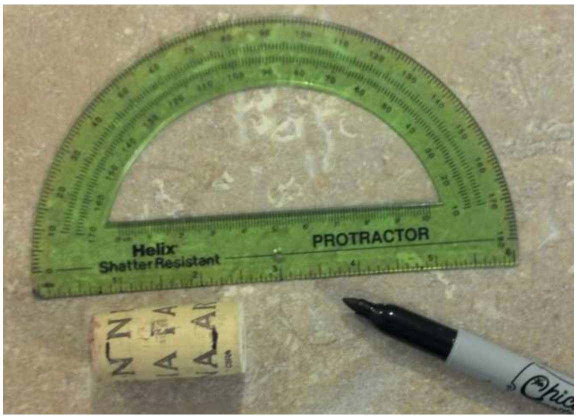
Turbine Hub Construction

What you need:

- Wine cork (actually cork, not plastic)*
- Stencils, see attached
- Tape
- Exacto knife
- Marker
- Ruler
- Serrated knife and cutting board
- Multi-meter lead

Instructions:

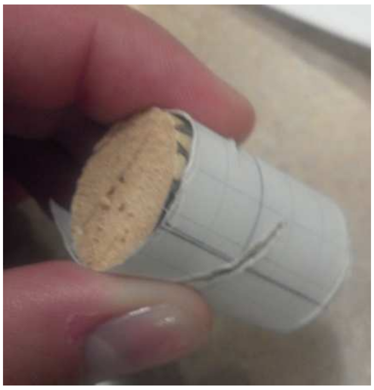
1. Mark 1¼" in the middle of the cork; try to get as much of the wine stains as possible outside the marks.



2. Use the serrated knife to cut off the ends of the cork on the lines you have marked.

3. Draw a dot at the center of one end of the cork. This marks the back of the hub.

4. Wrap the appropriate stencil around the cork and tape in place. The line that runs the length of the stencil should be closer to the front of the cork.



5. Using the Exacto knife, slice along the slanted lines on the stencil.

6. Remove the stencil and then cut out slots along the lines you just cut.

7. Use the multi-meter lead to punch a hole in the back of the cork, on the dot you previously drew, so that the hubs can be mounted on the generator.

8. Make sure you label each hub.

If you are careful when you take apart the students' wind turbines after they have completed the project, you can reuse the hubs. Then you only have to make them once, and then occasionally replace one or two.

*The easiest way to get enough corks is to call a wine bar or restaurant on Thursday and ask them so save the corks over the course of the weekend and then go pick them up on Monday or Tuesday.

Wind Turbine Construction (Baseline)

What you need (for one turbine):

- Posterboard, the thin cardboard, NOT thick like the tri-fold boards
- 3x Wooden craft sticks, standard size
- Baseline hub
- Baseline stencil
- Hot glue gun and glue
- Ruler
- Scissors
- Marker

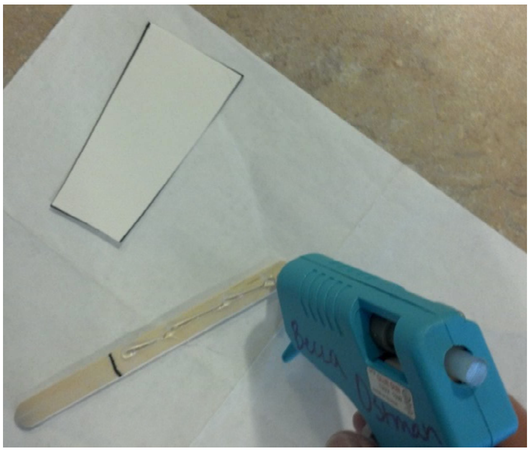
Instructions

1. Plug in the glue gun and place a piece of scratch paper under it.
2. Trace three blades onto the posterboard using the stencil.

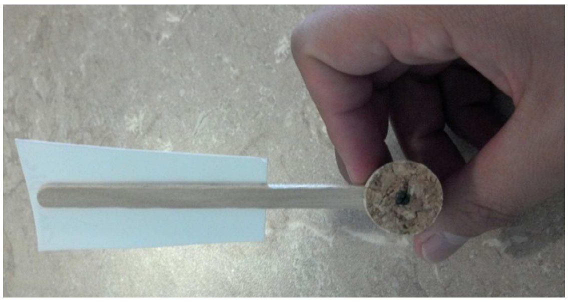
3. Cut out the three blades.

4. Measure and mark 1 ½" inches from one end of each wooden craft stick.

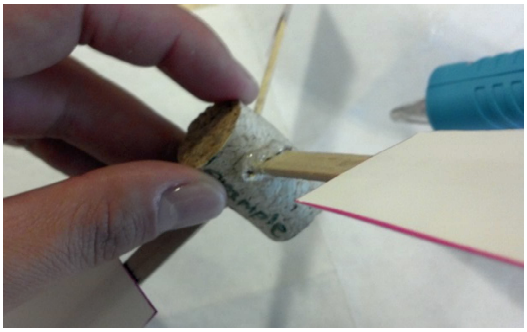
5. Glue one blade to the long side of each craft stick. Make sure to keep the stick centered on the blade.



6. Insert the blades into the hub; the wooden craft stick should face the back of the hub which is marked with the dot. Adjust the angle of the blades so that they are evenly spaced.

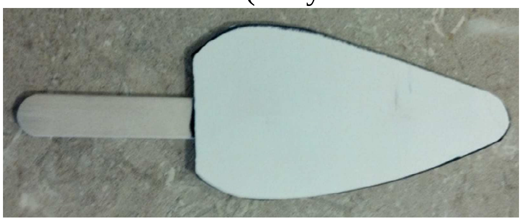


7. Glue around each blade where it is inserted into the hub.



Variations:

Round Blades – Use the Round stencil to trace out the blades; blades are oriented with the narrow end out (away from the turbine hub.



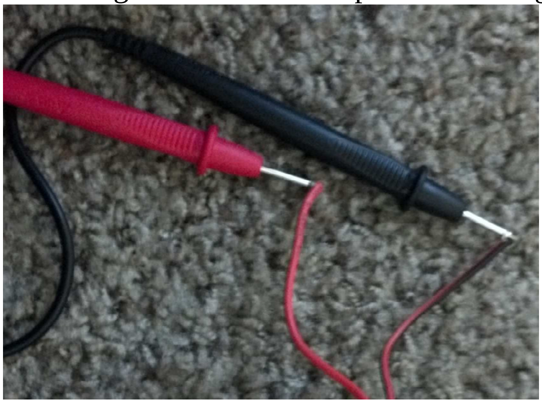
Long Blades – Use the Long stencil to trace out the blades.
4 Blades – Use a hub that has 4 slits for blades.
Small angle – Use a hub that has the slits for the blades cut at a different angle.
Lighter material – Use cardstock for the blade material, instead of posterboard.

These variations can easily be combined for the students' redesigned turbines. There is a Long, Round stencil for that combination and a Small angle, 4 blades hub for that combination.

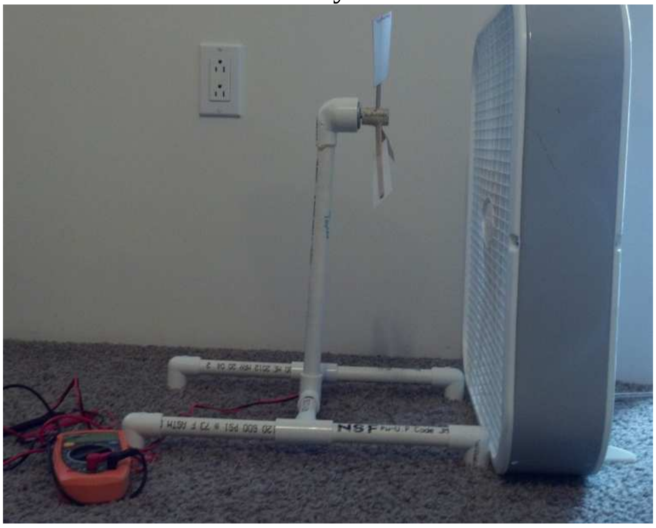
Testing Instructions

1. Push constructed turbine onto generator shaft.

2. Attach generator wires to multi-meter leads. Red to red and black to black. I recommend also using some electrical tape to ensure a good connection and cover the exposed leads.



3. Place turbine tower directly in front of box fan.



4. Turn the multi-meter on to measure voltage, order of magnitude 20 V setting. Make sure the red lead is plugged into the port that measures voltage. See next section on multi-meters.

Order of Magnitude 20 V

Voltage Measuring Terminal
(Red Lead)

5. Turn the fan on to the desired setting (1 for low speed, 3 for high speed). Record the voltage. There is going to be some fluctuation in the reading; let it settle for a few seconds and then estimate the average voltage output.
6. If you are having the students do the extension activities where they need to measure current, use the 200mA order of magnitude setting. This should not require changing the red lead to a different port, but this may vary by model of multi-meter. See next section on multi-meters.

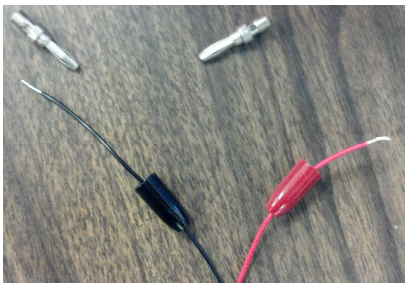
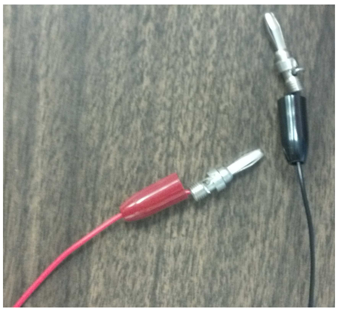
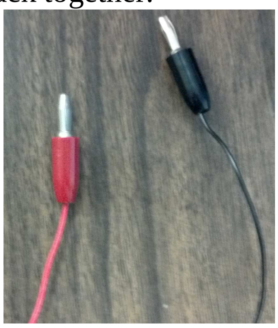
Order of Magnitude 200

Low Current Measuring Terminal
(Red Lead)

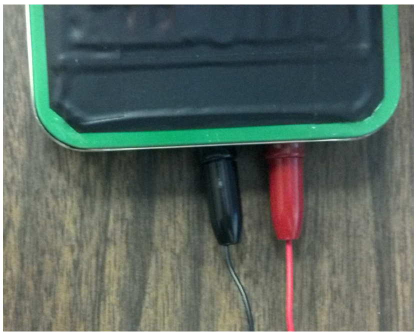
To use the LED indicator circuit from iRise:

7. Unscrew the male ends of the banana clips.

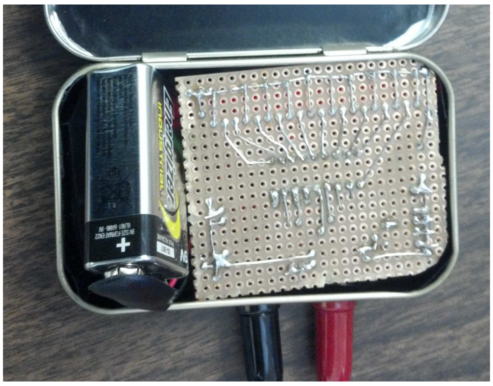
8. Thread wire through the plastic pieces then the holes in the metal pieces, matching the wire color to the banana clip color. Screw the banana clips back together.

9. Plug the banana clips into their respective (matching color) receptors.



10. Connect the battery inside the tin to the snap-on leads. Make sure you do this *after* connecting the banana clips or all the lights will go on and drain the battery. Similarly, make sure you disconnect the battery *before* disconnecting the banana clips.



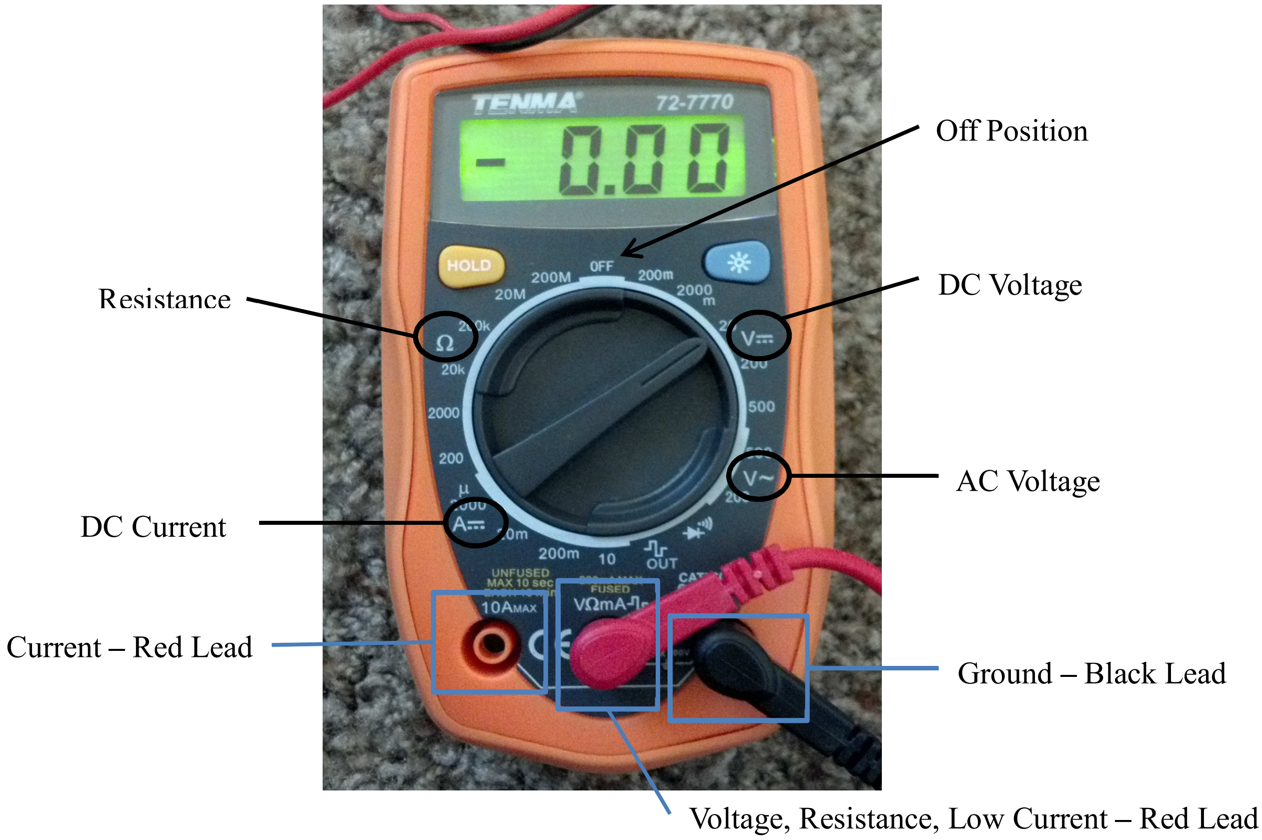
11. Turn on the fan, and watch the LEDs light up.

Multi-meters

This is a *basic* overview of multi-meters and their operation. However, it's important to realize that each multi-meter model is going to be slightly different. Read and keep for reference the box/instructions that come with your specific multi-meter.

- The **black** lead always goes into the ground terminal, which is the terminal on the right*, usually labeled COM.
- The **red** lead goes in one of the two left terminals, depending on what you are measuring. If you are measuring voltage (volts, V) or resistance (ohms, Ω), use the middle* terminal, labeled VΩmA. If you are measuring current (amps, A), you have the option of using the middle (VΩmA) terminal or the left* terminal, labeled 10Amax. The middle terminal (VΩmA) can only be used to measure low currents, generally on the order of hundreds of milli-amps or less. The left terminal (10Amax) can be used for all current measurements (up to 10 amps).
  *These positions vary by model, pay attention to the labels.
- When you are not using the multi-meter, make sure you turn it off to save the battery. Some models will automatically turn off after a certain amount of time not being used, but not all of them. Check the batteries before the lesson and have spare batteries on hand.

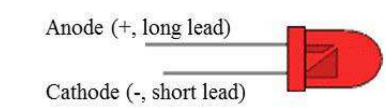
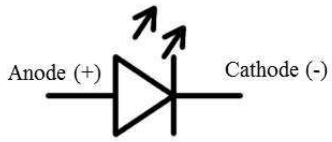
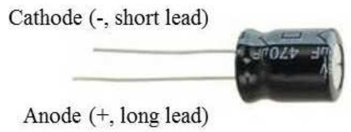
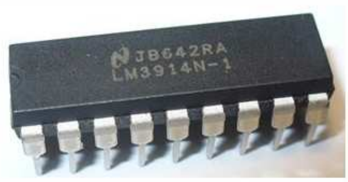
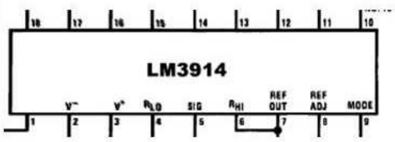
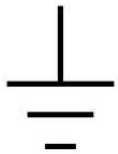
- This is the symbol for DC: ⎓. This is the symbol for AC: ∿. It is unlikely you will ever measure AC voltage in the classroom.
- The numbers around the outside of the dial indicate the order of magnitude of what that setting can measure. For example, for this lesson the wind turbines output 0-3 volts (V), so there are two settings that will give good readings: 2000mV or 20V. So, say a wind turbine is outputting 1.54 V. If 2000mV is the chosen setting, the multi-meter is going to read 1540 because it is giving a reading in milli-volts, so to get the measurement in volts you would need to divide by 1000. If the 20 V setting is chosen, the multi-meter will display 1.54 because it is giving the reading in volts and you will not need to do a unit conversion. If something that outputs higher voltages is being measured, the higher voltage settings will be needed and if something that outputs lower voltages is being measured, the lower voltage settings will be needed. If you do not know what order of magnitude you're going to measure, start at the highest setting and work your way down until you get a good reading. If the display is showing a 1 with no zeros, the measurement is too high for that setting (overloaded), go to a higher setting. If the display is showing zeros, but you know that you should get a reading, the setting is too high, move to a lower one.
- Symbols used to indicate order of magnitude:
  - M – mega, multiply by 10^6
  - k – kilo, multiply by 10^3
  - no letter/symbol, no conversion needed
  - m – milli, multiply by 10^{-3}
  - μ – micro, multiply by 10^{-6}
- If your reading is negative you have the leads reversed; switch the position of the pointy ends of the leads.



LED Indicator Circuits

These circuits are not necessary for the lesson. A multi-meter can be used to display output voltage to show students. However, having the wind turbines light up an LED is a really good visual to show that they actually produce electricity. Here are two different circuits that will make a good display; one simple one that just lights an LED and a more complicated one that lights more LEDs when more voltage is applied.

First, some notes about circuits:
Here is a table of some circuit components, what they actually look like and the symbol used to represent them in schematics.

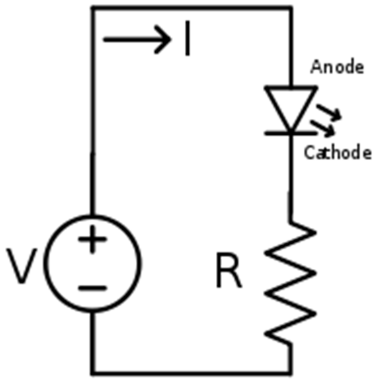
	Actual	Symbol
LED		
Resistor		
Capacitor		
Chip		
Ground		

It's easiest to build these circuits on breadboards, but if you know what you are doing you can solder them as well. All the parts can be purchased at Radio Shack or ordered online at http://www.digikey.com/

Simple LED Circuit
What you need:

- 1x Breadboard
- 1x red LED
- 1x resistor, probably around 100Ω

Schematic:



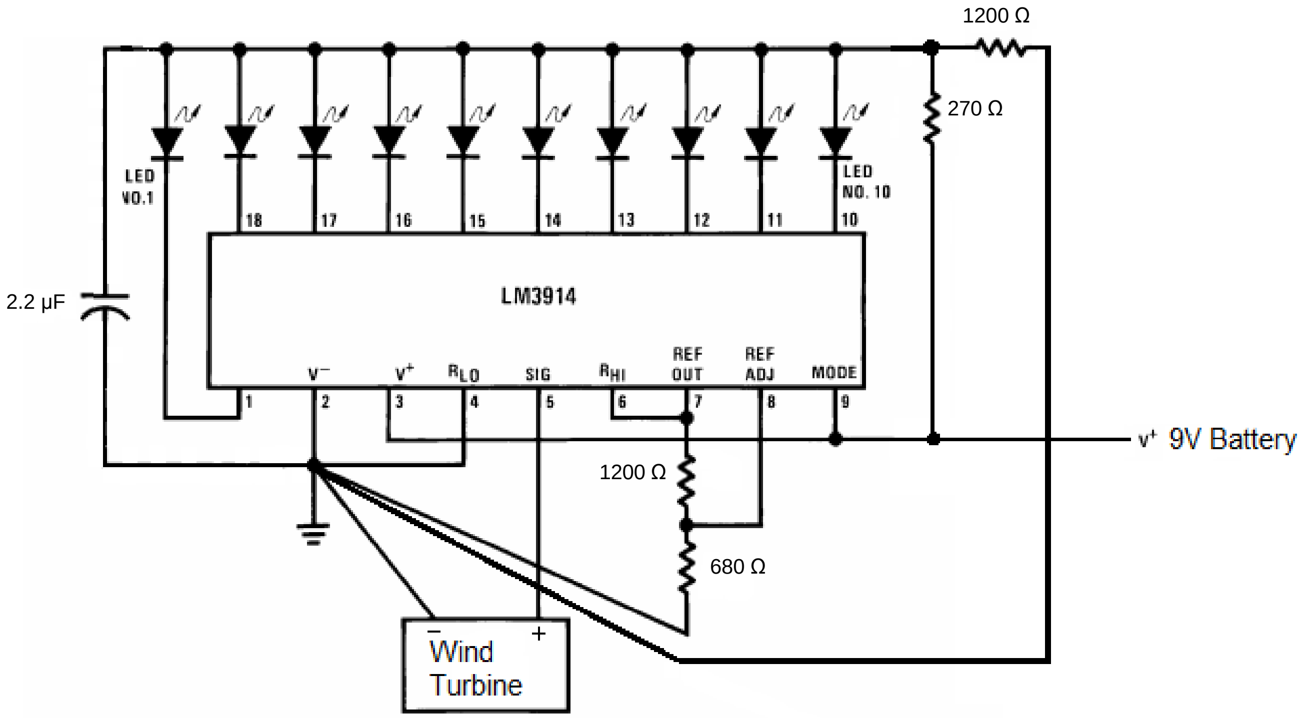
The voltage supply is the wind turbine, the red wire is + and the black wire is -. The minimum voltage required to turn on a red LED is around 2V, so the baseline wind turbine may not be able to light it up, even on the highest wind setting. You would need to test this before using this circuit. The resistor value determines the brightness, once the LED is on.

LED Voltage Indicator Circuit

What you need:

- Breadboard
- 1x LM3914N-1 chip
- 10x red LEDs
- 1x 2.2 μF capacitor
- 2x 1200 Ω resistors
- 1x 680 Ω resistor
- 1x 270 Ω resistor
- 1x 9V battery
- Snap-on battery leads
- Wire, a couple different colors is recommended for clarity, generally black for wires going to ground, red for voltage sources, other colors for things in between.

Schematic:



The chip is powered by the 9V battery. Use the snap-on leads to make connecting the battery easy; the red lead powers the chip (pins 3 and 9) and the black lead is the ground. The wind turbine's red line goes to pin 5 and the black lead needs to be connected to ground. The circuits that were built for iRise were contained in Altoids tins, and the wind turbines were connected using banana clips.